Storage Rot of Sugarbeet

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Contents

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Storage Rot of Sugarbeet

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Introduction

When sugarbeets are grown in climates where winter temperatures fall below freezing, the roots must be harvested quickly and then stored to await delivery or processing. Most of the sugarbeet acreage throughout the world is harvested this way and the roots stored for 30 to 150 days. In the United States, up to 75 percent of the crop may be stored outdoors in piles 5 to 7 m (17 to 22 ft) high by 55 to 67 m (180 to 220 ft) wide. These storage piles contain thousands of tons of roots. The stored root of a sugarbeet is living and obtains energy from its own sucrose that is lost during storage through normal respiration. Respiration causes about 70 percent and decay about 10 percent sugar loss. Sucrose also is lost through fermentation under conditions of low oxygen content because of poor ventilation, freezing and thawing cycles, and desiccation.

This review will be restricted to the decay problem of healthy roots stored under usual commercial conditions. It will not be concerned with the decay of weakened or dead tissue brought about by the physical factors listed above. Dead plant tissue is decomposed by saprophytes. Controlling this loss obviously can be attained by eliminating the physical factors that interfere with normal root metabolism. A more formidable task is the reduction of rots in healthy sugarbeets that have been stored under the best environment, which technology has to offer.

The amount of sugar lost from stored sugarbeets as a result of pathogen activity has been assessed twice in the United States (*8*). The surveys were made at a Moorhead, Minn., sugarbeet factory in the processing seasons of 1974-75 and 1975-76. During a 128-day survey of the first processing season (campaign), there were 414,427 metric tons (456,820 tons) of sugarbeets processed of which 1.2 percent was decayed tissue. This indicated that 5,583 tons of rot went into the factory. Figure 1 depicts an estimate of daily losses.

This rotted tissue had a potential sugar yield of over 500,000 kg (1.1 million pounds). High levels of impurities such as reducing sugars exist in rotted tissue. These impurities interfere with crystalization of sucrose. So it was estimated this rotted tissue caused an additional 808,800 kg (1.8 million pounds) of sucrose to go into molasses; therefore, the total sugar loss at this

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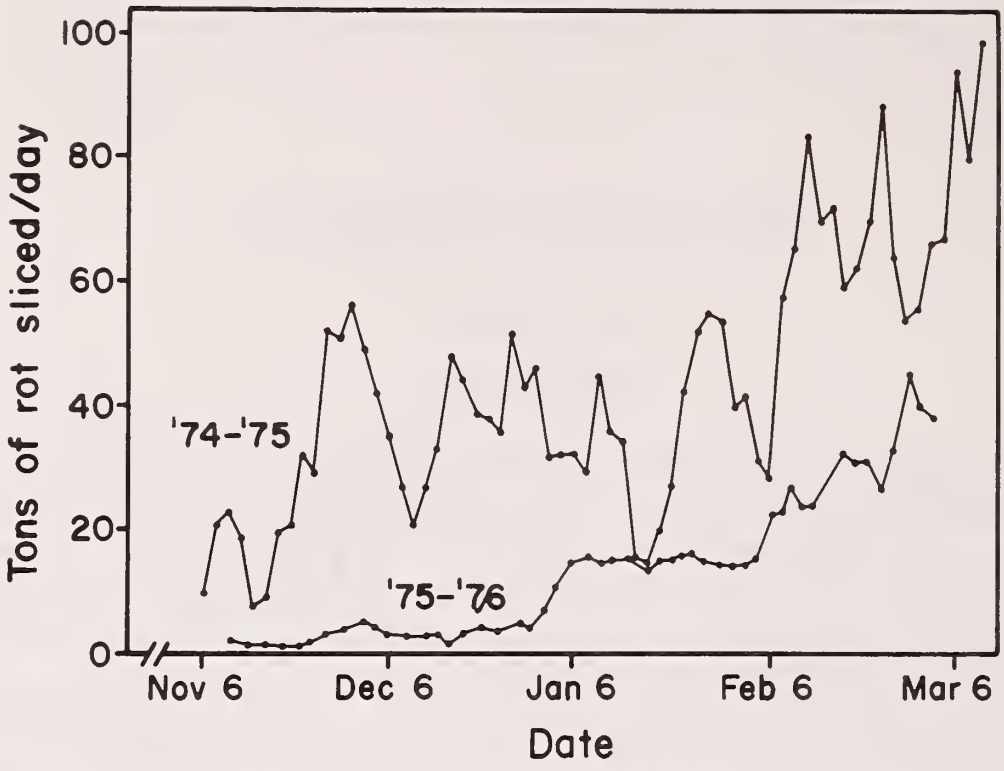

Figure 1.—A running average of the tons of rotted sugarbeet tissue that was processed at Moorhead, Minn., factory in 1974-75 and 1975-76.

one factory was over 1.3 million kg (2.9 million pounds). Conceivably, similar losses occurred at five other factories in the Minnesota-North Dakota growing region. This means that 787,700 kg (17.4 million pounds) of sugar was lost during the processing season of 1974-75 in the Red River Valley of the North (Minnesota and North Dakota). Results from a 117-day survey of the 1975-76 processing season indicate that the losses were only 27 percent of that in 1974-75. These losses usually become significant beginning in mid-December.

In Russia a 24 percent reduction in the amount of sugar extracted from stored sugarbeets after January 1 was reported for the processing seasons of 1957-58 and 1961-62 (*58*).

Casual Pathogens

Most of the decay observed in beets at the Moorhead factory was caused by fungal pathogens, of which *Phoma betae* and *Penicillium claviforme* were most prevalent. *Botrytis cinerea* is recognized as the most important storage rot pathogen throughout the world (*19,23,26,27,40,54*). Observations in the Red River Valley since 1969 have not supported the importance of *B. cinerea*. In the Moorhead survey this fungus was found at a low frequency (*8*). This phenomenon is probably due, in part, to the antagonistic capability of *P. claviforme* toward *B. cinerea* (*7,56*).

Sugarbeet isolates of *P. claviforme* inhibited the growth of *B. cinerea* in vitro and in vivo (*7*). *P. betae* and not *B. cinerea* also predominated among isolates taken from diseased sugarbeet roots in Alberta, Canada (*13*). Possibly the low level of *B. cinerea* reported in Canada also could be due

to this antagonism. Other fungi of lesser importance include species of *Penicillium, Aspergillus, Fusarium, Rhizopus,* and *Pythium ultimum* (*19,26,38,57*). Bacterial pathogens are important only when the beets are stored under warm conditions. Once the pile temperatures have cooled down, bacteria become unimportant except as fermenters under low oxygen levels.

Phoma betae.—*Phoma betae* is potentially the most dangerous storage rot pathogen because its disease cycle is closely associated with the life cycle of the sugarbeet (fig. 2). This pathogen infects the seed, especially in humid seed production areas or when windrows are rained upon. Seedlots with 40 to 50 percent infection are not uncommon under these conditions (*11*).

When the seeds are planted, some of the seedlings may damp-off, but others may continue to grow and produce a normal, healthy-looking root. The fungus is still inside the crown tissue of the sugarbeet and, after the beet is harvested and placed in storage, decay can proceed (*17,18*). Decay usually does not occur until the beets have been stored for about 80 days. The sugarbeet also requires 70 to 90 days of exposure at low temperatures to induce flower and seed development upon regrowth of the root. The similar time required for both of these events suggests the need for research to determine if this is a coincidence, or if increased susceptibility to rot and induction of flowering are related.

The amount of seed infection is correlated with the amount of storage rot that will occur many months after the seed has been planted (*17*). *P. betae* can be eradicted from seed with hot water (*25*), thiram steep (*37*), and mercury steep (*10*), but these treatments have not been cleared for use in the United States. This work has not been carried further to measure the effect of seed treatment on storage rot. Systemically active chemicals applied to seed plants in the field to reduce seed infection have not been attempted but appear desirable.

Seed produced in foreign countries pose a special problem. In 1973, sugarbeet growers in the Red River Valley of the North purchased the American Crystal Sugar Company[2] and formed a cooperative. The new cooperative adopted an open-seed policy whereas under the old corporation the growers were required to purchase their U.S. grown seed from American Crystal. Under the new policy, European sugarbeet seed companies established markets in the Red River Valley. Seed is now imported from several production areas in Europe, thereby introducing isolates of *P. betae*. This situation existed before World War II when the United States received most of its seed from Europe. Thus, a heterogenous population of *P. betae* with a wide range in virulence (*53*) is perpetuated in the United States.

During the growing season, *P. betae* produces leaf spots on the older, lower leaves of sugarbeets, but the disease is not economically important in the United States. In 1937, inoculation tests confirmed that both leaf spot

[2] Commercial names are used in this publication solely to provide specific information. Mention of them does not constitute an endorsement by the U.S. Department of Agriculture over other firms not mentioned.

that had been attributed to *Phyllosticta* and root rot was actually caused by *P. betae* (*45*).

The fungus is able to survive in debris in field soil up to 26 months after the sugarbeet seed have been planted and in soil all year in sugarbeet storage yards (*9*). It was detected in debris that fell from piler booms as

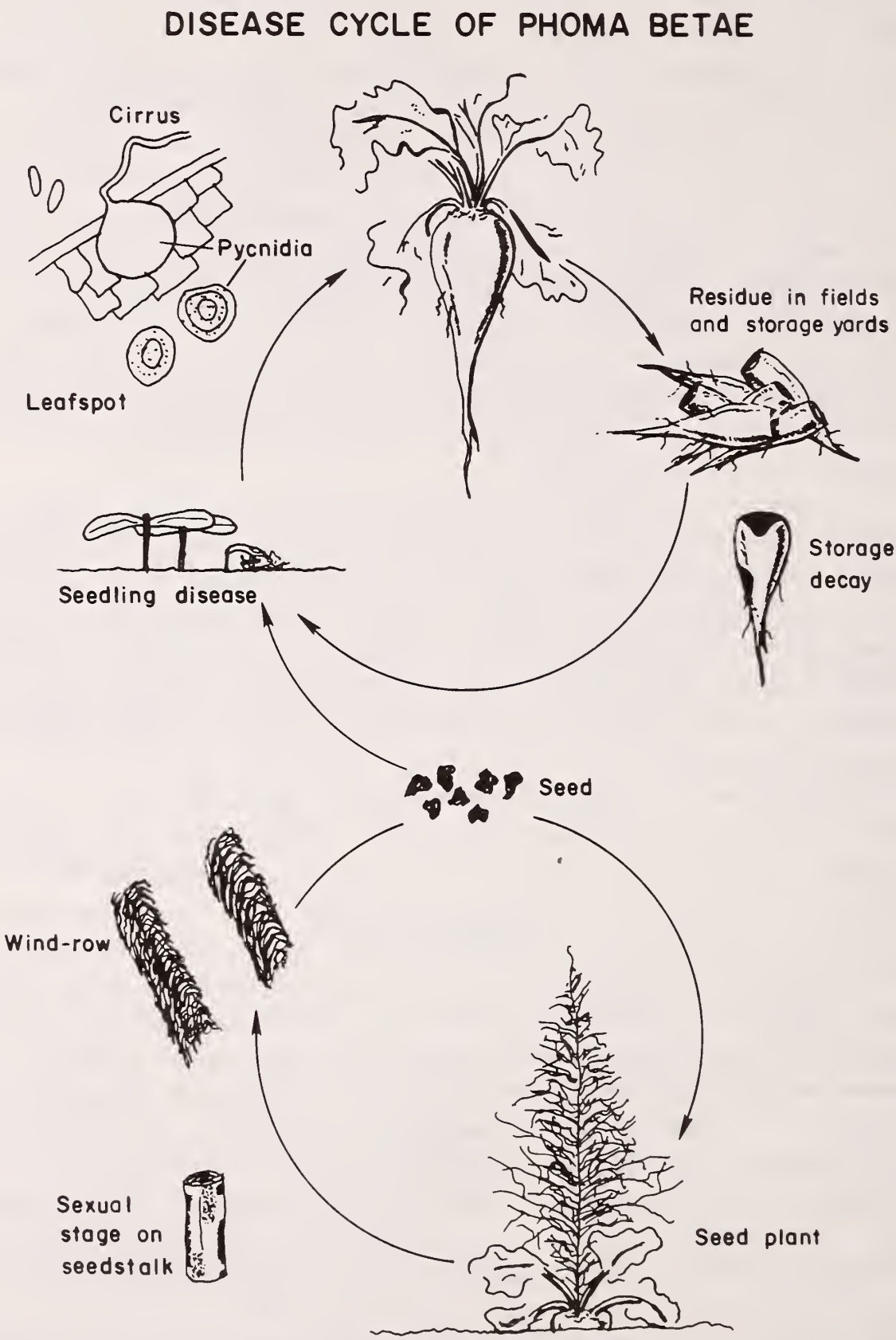

Figure 2.—Disease cycle of *Phoma betae*, a major cause of sugarbeet storage rot, wherever sugarbeets are stored throughout the world.

Figure 3.—Rot caused by *Phoma betae* with the characteristic cone-shaped progress of the rot and small pockets of tissue lined with white fungal growth.

sugarbeet piles were being constructed (*6*). Therefore, *Phoma*-laden debris being brought in from an infested field could be deposited on beets brought in from noninfested fields during the piling operation.

The perfect or sexual stage, *Pleospora bjoerlingii* Byford, develops during the winter on seedstalks in the field and may permit the fungus to survive in seed growing areas. The perfect stage has not been grown in isolated culture so this portion of the pathogen's life cycle has not been thoroughly studied.

Phoma betae also can cause a crown rot or a heart rot in the field in mature plants under physiological stress. Alkaline soils of pH 7.8 or above favor this disease. Ten isolates were examined and no differences in pathogenesis were evident. The conclusion is that the variation in heart rot was due to differences in the physiological disturbances (*24*).

In the storage rot phase of the disease cycle, four isolates differed by as much as 50 percent in the amount of tissue they could decay under controlled conditions (*53*). Aggressiveness varied according to temperatures of the storage period. Two isolates possessed similar aggressiveness although they differed significantly in morphology.

The first indication of phoma rot usually is in the center of the crown, from where it spreads downward often in a cone-shaped pattern into the main taproot (fig. 3). Rotted tissue is black with occasional pockets lined with white mycelium of the fungus. The spores are exuded from small, black fruiting bodies (pycnidia) in a sticky, gelatinous matrix and are not readily disseminated by wind.

Penicillium, sp.—Many species of *Penicillium* cause rot generally referred

to as mold, but *P. claviforme* is the most important in the North Central Region of the United States. Rot is usually associated with wounds, and the fungus can occur in tissue rotted by *P. betae*. Rot caused by *P. claviforme* can be identified by fungal structures of white tufts or coremia that are produced on brown, rotted tissue (fig. 4). These spores can be carried on wind currents to infect other roots in storage.

Botrytis cinerea.—*Botrytis cinerea,* the most aggressive of these fungal pathogens, is able to rot tissue quickly over a wide temperature range (*54*). Rot caused by this fungus can be identified by the occurrence of dark-brown to black, round sclerotia, and gray masses of spores. The sclerotia are 2 to 5 mm (0.1 to 0.2 inches) in diameter and form in groups on the rotted tissue (fig. 5). Rotted tissue is dark brown or black, in which case *P. betae* could be present with *B. cinerea*. *B. cinerea* produces dry spores that can be wind disseminated to infect other roots in storage piles (fig. 6).

Predisposition of Roots to Infection

Wounds

Incidence of decay is much greater in roots that have suffered wilting, frost damage, wounding during harvest procedures, or from diseases during

Figure 4.—Rot caused by *Penicillium claviforme* showing columns of fungal growth bearing clumps of dry spores. The spores are disseminated by wind and carried to other stored roots to initiate infection.

Figure 5.—A sugarbeet rotted by *Botrytis cinerea* showing the round masses of dense fungal growth (sclerotia) produced by this fungus.

the growing period. Wounds predispose roots to the greatest amount of initial decay. Before modern-day mechanical harvesting procedures, sugarbeets were lifted from the soil with a hooked knife. The roots were speared with this hook and the leaves and crown (stem) were removed with the knife. Decay originated quite often in the damaged areas caused by this hook (*51*). Decay also develops on the surface of the cut crown.

A study in 1930 reported that most of the rot in stored roots in Utah was in the crown, and that this rot, caused mostly by *P. betae,* increased as the amount of crown that was removed increased (*52*). Traditionally, crown tissue has been removed because it is lower in sucrose than the main taproot and contains a high concentration of impurities, which contribute to the formation of molasses and interfere with the crystalization of sucrose during processing. But the rot that was developed during storage in wounded crown tissue lowered the value of what was considered a properly crowned root to less than that of what was considered an improperly or high crowned root. The suggestion was made that roots destined for storage would maintain a higher quality if topped high rather than low (*52*).

Today, the first harvest operation is the mechanical removal of the leaves and petioles followed by mechanical removal of the crown area with a knife. Artschwager and Starrett (*2*) reported that little decay resulted from roots cut through the crown because of specialized anatomical structure of this region. More recent and extensive data, however, has shown that removal of the crown tissue exposes pith tissue within the crown and that the pith is the most susceptible tissue in the root (*5*).

Figure 6.—The fluffy, gray fungal growth is that of *Botrytis cinerea* and contains dry spores that can be carried by wind to infect other roots.

Two to three times more decay may be expected to occur in storage in roots that have been partially crowned to expose susceptible tissue (*5*). The amount of decay originating at wounds at the tip of the taproot and body of the root does not increase during the storage period, but decay in the crown area continues to advance and eventually accounts for a major portion of the total decayed area (fig. 7) (*8*). Moreover, removing crown tissue also causes a sharp rise in respiration which further contributes to sucrose loss (*16,50*).

Russian work more than 35 years ago recognized increased storage rot in roots that were topped by the conventional method (*41*). They recommended crown removal in such a way as to not expose pith tissue.

Recent research has shown that with proper management of available nitrogen in the field, sufficient sucrose can be extracted from intact crowns to warrant discontinuance of crown removal from roots intended for storage (*1,12,15,19*), especially those roots to be stored for 60 or more days.

Soil Fertility

Limited information is available on the effects of soil fertility on storage rot of the sugarbeet. Roots grown in soil low in phosphate were more susceptible to *P. betae* than roots grown in soil with adequate amounts of phosphate. Phosphate fertilization also seemed to reduce the loss of sucrose because of respiration (*35*). Sugarbeets grown under low nitrogen fertility were more susceptible to *P. betae* than those grown under adequate nitrogen fertility (*21*). Results from Russia have shown that roots grown in adequately fertilized

soil are more resistant to *B. cinerea* than roots grown under low fertility conditions (*33,34*).

A standard practice, where feasible in the United States, is to make available only enough nitrogen to provide adequate top growth during most of

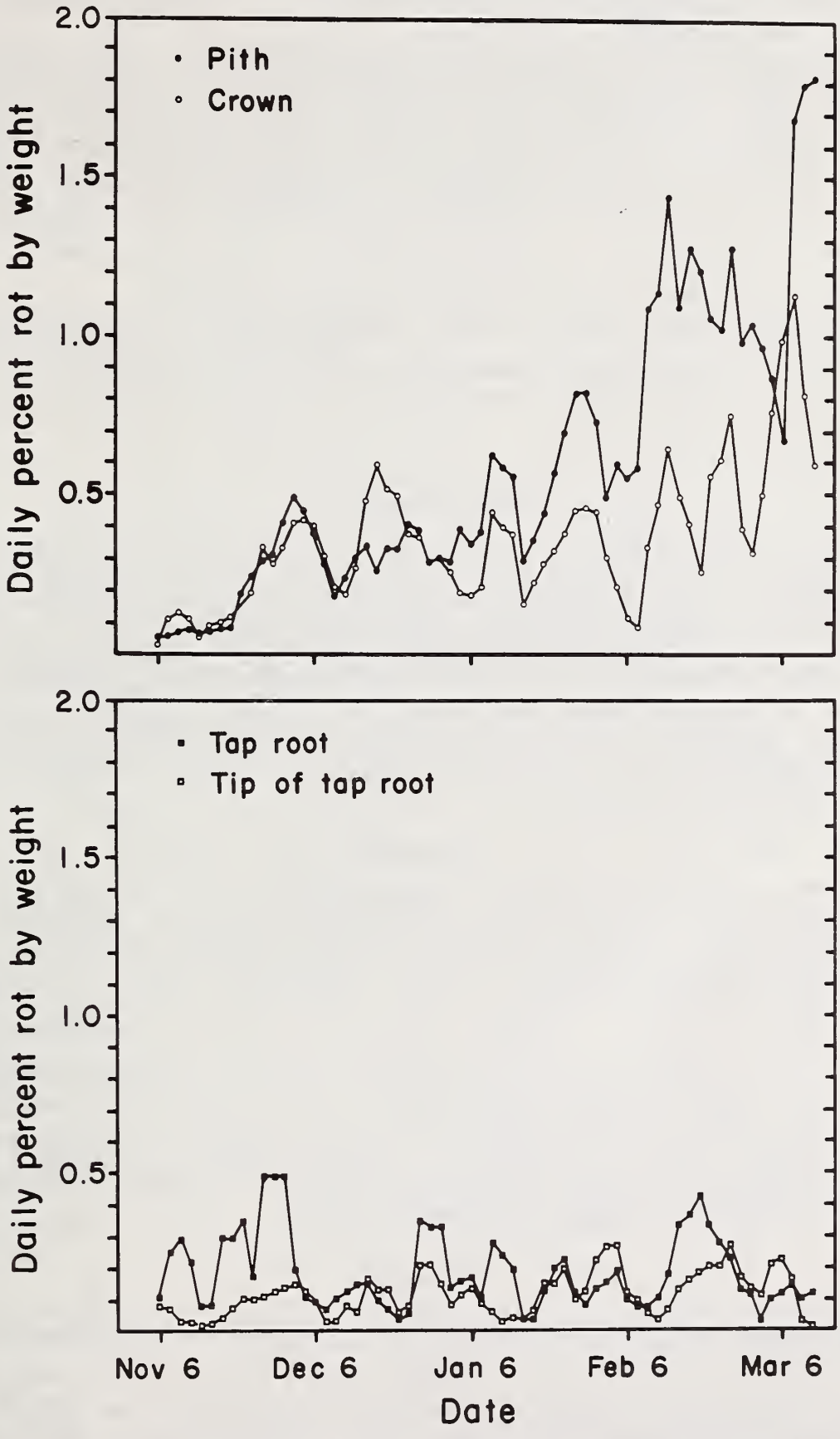

Figure 7.—The amount of rot classified as to which part of the root was affected, pith, crown, taproot, processed daily at a Moorhead, Minn., factory during the 1974-75 season.

the growing season. The intent is to have the nitrogen supply depleted from the soil a few weeks before harvest. This reduces top growth and causes more sucrose to accumulate in the root instead of being consumed as an energy source of growth.

The production of roots with a low nitrogenous content is highly desirable because these compounds interfere with the extraction of sucrose during processing. But the above research indicates that high quality roots desired by the processor are more susceptible to storage rot than roots of lower quality. This interaction is recognized in Russia where they suggested that selection for resistance to storage rot pathogens proceed simultaneously with selection of sugarbeet lines that have low levels of impurities.

When sugarbeets are grown in boron-deficient soils such as those prevalent in Michigan, a physiological disease called heart rot may develop (*3*). These roots also are more susceptible to heart rot caused by *P. betae* and may be damaged further by rot when placed in storage (*24*).

Other Diseases

Diseases in the field may predispose roots to increased storage rot. A 50 percent reduction existed in storage rot of harvested roots from plants that had low compared with high levels of cercospora leaf spot in the field (*49*). Thus, the degree of field leaf spot infection closely paralleled the number of harvested roots that rotted in storage. Common storage rot pathogens observed in the test included species of *Botrytis, Fusarium, Penicillium*, and *Phoma* (*49*).

Drought

The water status of the root also affects storage rot (*55*). Roots that lose excessive moisture after they are harvested and placed in storage are more susceptible to storage rot than are fully turgid roots (*13,20*). An increase in the amount of root rot in storage caused by *P. betae* was associated with low rainfall in northern Utah and southern Idaho (*44*). In Russia, genotypes resistant to botrytis storage rot were observed to maintain higher turgor than susceptible genotypes during periods of drought (*48*). Leaves of susceptible plants wilted sooner than resistant, so this behavior might be used as a method of selecting storage rot resistant roots.

Freezing

Roots stored outdoors in most climates are exposed to freeze-thaw cycles. Once the root is frozen it must be kept frozen. The root stores well when frozen. This method is coming into use in the Altai region of the U.S.S.R. and in the Red River Valley of the North. After the root thaws, cell contents diffuse out of dead cells and the tissue decays quickly.

Maturity

The maturity of the root influences its susceptibility to storage rot. Research in Russia has shown root resistance to *B. cinerea* decreases as the plant matures; young beets were less susceptible than older ones irrespective of date of sowing or harvesting (*39*). Results from the United States, however, indicated that resistance to *P. betae* and *B. cinerea* increases with maturity.[3] These conflicting results could be due to soil fertility, which is known to affect the rate at which the sugarbeet reaches technical maturity.

Control

Methods used to reduce storage rot of sugarbeet include fungicides, resistant cultivars, and controlled environment. An attempt to control storage rots in the United States began in 1950, but interest was not renewed until 1970.

In the Soviet Union, with their vast acreage of sugarbeets of which millions of tons must be stored each year, storage rot destroys roots intended for processing and mother roots intended for seed production. Thus, the Soviets began developing cultivars resistant to storage rot in the 1930's and over the years have tried various chemicals to control pathogens in the storage piles. Russian breeders have developed lines of sugarbeet resistant to storage rot and to trench rot.

Russians produce seed from mother roots which are harvested in the fall and buried in trenches. These trenches cover an area of 7,000 hectares (17,500 A) (*36*). The roots covered with approximately 1 meter of soil are uncovered in the spring and replanted for seed production. Many roots are lost to decay, freezing, and suffocation during the storage season. Therefore, some resistance to storage rot should be present in these roots to insure an adequate seed supply. More recently, the Russians have developed commercial cultivars resistant to storage rots, and have over 200,000 ha (500,000 A) under cultivation.

Attempts to control storage rot with chemicals have not been very successful. Milk of lime or calcium hydroxide, a by-product of the factory process, has been applied to sugarbeet piles to increase the pH of the surface of the sugarbeets and render this area unsuitable for growth or establishment of a pathogen. The white surface also reflects sunlight and helps to cool the roots. This practice is routinely used in the U.S.S.R. early in the storage season (personal observation of author). Recently Khelemskii and others (*31*) have demonstrated the usefulness of thiosulfonic acid esters against storage

[3] Data from 1 year's experiment show that the resistance to *P. betae* and *B. cinerea* of field grown roots increases with age. This resistance decreases after the roots have been stored.

rot. In the United States thiabendazole is being used on a trial basis. Preliminary results appear encouraging.

Results of the storage of sugarbeets under protective covers also are encouraging. The use of insulated steel buildings, plastic film canopies, and air-supported plastic film bubbles (30) eliminates damage caused by freeze-thaw cycles and desiccation (fig. 8).

Beets stored within these structures are cooled by forced-air ventilation. The humidity is high. Fungal pathogens, particularly *Penicillium* sp. and *B. cinerea,* sporulate in the humid environment. The dry spores are distributed on continually moving air currents and deposited on other roots to renew the disease cycle. Thus, these storage structures function as giant incubators for storage rot pathogens. The use of resistant cultivars and fungicides for long-term storage within these structures would help to alleviate what appears to be the last major obstacle to an extended beet storage period.

Two problems exist in trying to control storage rots of sugarbeets. One, we must always be aware of fungicide residue problems on sugarbeet material. Many fungicides will control storage rot pathogens, but most of these will leave a dangerous residue in the sugarbeet pulp and accumulate in the recycled water system of the factories. The second problem concerns *P. betae.* Because this fungus is seedborne and remains within healthy tissue throughout the life of the sugarbeet, breeders also suffer annual losses of stored mother roots. Because the fungus is embedded within host tissue, it can not be reached with a simple contact type of fungicide. Protecting the seed from infection, or eradicating the fungus from the seed seems advisable by applying systemic fungicides to seed plants in the field.

Storage of sugarbeets under structures will provide more information on the use of controlled environments. The least amount of sucrose loss, sprouting, and fungal growth was observed when roots were stored in 6 percent CO_2 and 5 percent oxygen at 3° C (28). Gaseous fumigants or fungicides also may be considered.

When excessive rains occur in the fall, soil adhering to the roots can restrict free air movement in storage. The suffocated sugarbeet soon deteriorates. Washing the roots will remove the soil and allow free air movement, but decay caused by pathogens will not be retarded and may even increase (*14*).

Creating an environment conducive to wound repair also is important. Healing of harvest injuries and the formation of barriers (suberization) to microbial invasion are enhanced by proper temperature and air movement (*55*). Wound periderms will develop within 10 to 14 days. The proper environment is 10° C, a relative humidity not below 95 percent, and an air velocity of 0.08 to 0.25 m/sec (16 to 49 ft/min) (*29,32*).

Evaluation of various commercial cultivars in W. Germany (*14*), France (*42*), and in the United States (*4*) showed that considerable variability exists in reaction to storage rot pathogens. However, the level of resistance in cultivars is not adequate. Apparently, improvement in resistance can be made

Figure 8.—Two methods of protecting stored sugarbeets: *top;* air-supported plastic bubble with an air-lock entrance for trucks; *bottom;* plastic film on the sides and supported by rafters on top of a beet pile.

through breeding (22). Most Russian plant pathologists and plant breeders screen for resistance to only *B. cinerea* because they claim that resistance to this fungus also conditions resistance to other important storage rot pathogens (*47*). The result of 42 years of selection and breeding work in Russia has culminated in root material that will not decay when placed on pure cultures of *B. cinerea* for up to 65 days, compared with susceptible tissue which is completely rotted in 8 to 20 days (*46,58*). Commercial cultivars are in use which sustain 1.5 to 2 times less damage from storage pathogens than non-selected cultivars (*34,43*).

Various inoculation techniques have been used in the laboratory to evaluate roots for resistance. Toothpick inoculation and the placement of slices of sugarbeet root tissue on pure cultures of the pathogen have been successful (*23*). A satisfactory method has been used for the past three years in our laboratory. Cores of tissue from sugarbeets are removed with a cork borer, cut into desired lengths, and then placed on end on pure cultures of *B. cinerea, P. betae,* or *P. claviforme* for 2 weeks at 22° C. Inoculations are done in duplicate, placed in separate chambers, and each of the two cores for each fungus must give the same resistant reaction for selections to be made. The 2-week incubation, although longer than the standard 4 to 5 day Russian incubation, places more disease pressure on the tissue and, hopefully, will result in higher levels of resistance.

The development of storage rot resistant breeding lines was begun in the United States in the early 1950's (*22,23*). Sources of resistance to *P. betae* and *B. cinerea* were identified, indicating that breeding for resistance would be possible. This program was not pursued.

The need for storage rot resistant lines took on new importance in the 1970's, and a search for resistance to various storage rot pathogens was begun in 1972. Breeding programs are in progress within private sugar companies and within the U.S. Department of Agriculture. United States breeding lines with resistance to *P. betae, B. cinerea,* and *P. claviforme* currently are becoming available, and attempts will be made to incorporate this resistance into commercial cultivars.

Sugarbeet cultivars that must be stored should possess two qualities in addition to desirable agronomic characters. Such cultivars should have a low respiration rate, and they should be resistant to storage rot. Some concern exists that combining these two characters into a commercial cultivar may lower the root or sucrose yield of the resultant hybrid. This phenomenon has occurred when resistance to other pathogens was bred into commercial cultivars. This remains to be determined, but the value of the storage cultivar cannot be assessed until it has been in storage for at least 80 to 100 days and compared with a standard commercial cultivar. A commercial storage variety may turn out to be slightly lower in yield than a nonstorage variety at harvest. Therefore, a storage cultivar will be of value and used by the industry only if the cultivar possesses a higher extractable sucrose content than a nonstorage cultivar after storage.

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